SOME RECENT ADVANCES

IN

TINPLATE MANUFACTURING PROCESSES

W. E. HOARE, D.Sc.(Eng.), F.I.M., A.I.Prod.E.
Head of Tinplate Section, Tin Research Institute

TIN RESEARCH INSTITUTE

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An address given at the
Congresso Imballaggi, Parma, Italy
September, 1954

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TIN RESEARCH INSTITUTE
FRASER ROAD, PERIVALE, GREENFORD, MIDDLESEX

January, 1955

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INTRODUCTION

DURING the last quarter-century the tinplate manufacturing industry has seen changes both radical in nature and great in extent. In the year 1929, world production was three and a quarter million tons, the electrolytic process was a laboratory curiosity, and only some five thousand tons of tinplate was produced by the then highly novel continuous cold-reduction process.

To-day production is running at approximately six million tons annually, electrolytic tinplate alone approaches three million tons, and over 80 per cent. of tinplate base is made on wide strip mills by the continuous process. Alongside these impressive developments there have occurred notable technological advances in steel metallurgy, annealing practice, design of pickling and tinning installations and in the important problems of quality appraisal. In the course of a short address it is not possible to review all these developments in detail. An attempt is made, however, to place some of them in perspective and to emphasise the more important aspects.

In England we have a saying "he who pays the piper calls the tune", which equivalently in Italian is "Colui che paga il cantante, sceglie la canzone". Thus, we must always remember that the principal and all-important use of tinplate is for the manufacture of containers for the preservation and transport of food, beverages and other merchandise of a perishable or fragile nature. It is the container manufacturer and the packer who "calls the tune" and it is to his requirements that the long-viewed manufacturer will defer.

The user requires in tinplate two fundamental abilities or characteristics: the ability to be *made* into a useful container; and the ability to provide a container which will efficiently protect, preserve, and help to sell whatever may be packed in it. On the one hand we have requirements such as ductility, solderability and truth to dimensions; and on the other hand characteristics like strength, corrosion resistance and aspect. To these factors must be added the all-important economic ones of cost and availability. Tinplate must be inexpensive, since most containers made from it are for "single service and throw away". Moreover, it must be continuously available when needed, such as in seasons of flush and harvest.

Tinplate is a dual material and its value to the user depends on the individual qualities of both the steel basis and the tin coating. For the steel base, the important characteristics are chemical composition, grain size, and carbide distribution; while for the tin coating such properties as thickness, amount of tin-iron alloy, and continuity are vital. In certain applications of tinplate the effects of these various factors may be algebraically additive. Thus the use of highest quality steel base can sometimes permit reductions of tin coating weight; and, *vice versa*, a heavier, high-quality tin coating may mitigate inadequacies of steel quality, though it cannot affect strength or fabricability. It can certainly be inferred that some of the modern refinements of tinplate base manufacturing technique would not have been developed had it not been for the increased use of the thinner electrolytic coatings which increased the need for such refinements.

THE STEEL BASE

Possibly the most obvious characteristic of the steel base is its chemical analysis. For the purpose of the present discussion this means its contents of carbon, silicon, manganese, sulphur, phosphorus and nitrogen, and also of copper and other residual elements. Composition must always depend to a considerable degree on type of ore and pig iron, quantity and quality of scrap available, and the type of primary steel furnace with which the works is equipped. To this extent it may be said to be outside control of the tinplate man whose influence is perhaps permitted to start at the ingot-casting stage.

In the U.S.A. for example, circumstances have permitted the development of three principal grades of steel composition for tinplate, and these are designated types L, MR and MC. Other grades admittedly exist, such as beer-can end-stock and aluminium-killed steel for extra deep-drawing work, but these are definitely specialities. The differences in composition ranges of the L, MR and MC types lie only in their contents of phosphorus and of the residuals copper, nickel, chromium, molybdenum and arsenic. Manufacturers may, of course, have their own internal disciplines of composition, but these are domestic matters and must not concern us.

In other areas, different criteria must perforce be used and, as another example, in countries where the Thomas process is widely employed, control of nitrogen may be particularly important. Nitrogen is a more active hardener even than carbon, and control is vitally necessary in the manufacture of the softer and more drawable grades.

Broadly, from the points of view both of corrosion resistance and of fabricability, the lower the contents of sulphur, phosphorus, nitrogen and other residuals the better. Within the economic limits imposed from above, the manufacturer does his best in this respect. Segregation of the metalloids in the solidifying ingot complicates his problems, but much careful study has been given to factors influencing the desired balance between the criteria of yield, surface quality and homogeneity. The increased use of

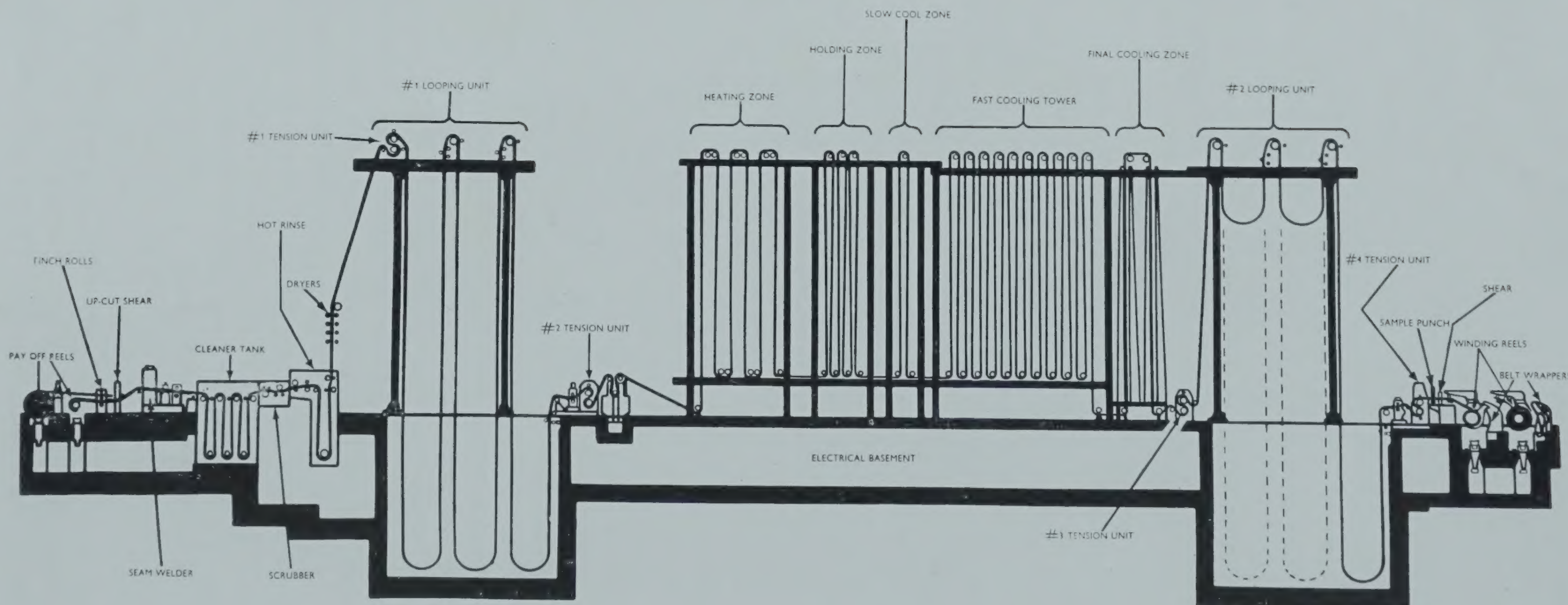
capped steel, the development of stabilised steels and the greatly improved understanding not only of the mechanism of segregation but also of the effects of the segregates on ultimate quality, have contributed notably to the technology of tinplate steel manufacture. Thus, in a typical rimming steel ingot, with its pure outer skin and reasonably good yield, a degree of sulphur and phosphorus segregation exists which makes the bottom half of the ingot better, for many though not all purposes, than the top. Thus, bottom-cut slabs can often, with profit, provide the basis material for tinplate for more critical packs. I must however hasten to dissuade users from demanding bottom-cut slabs for everything. You will quickly perceive that such a practice would result in tinplate boxes becoming, in short space, exactly twice as costly. It is such matters that make consultation between user and manufacturer so desirable: each must understand the others' problems in order that the optimum material from both economic and technological viewpoints, shall be provided.

It is not possible to speak at this time of the many interesting developments in rolling mill practice; culminating, as they have done, in such remarkable figures as production from a single hot strip mill of 250,000 tons in a month, and cold-mill delivery speeds of the order of 2,000 metres per minute. Following the remarks on steel base composition however, the effects of hot-mill conditions on final steel base *structure* must be briefly mentioned.

Any visitor to a modern hot strip mill cannot fail to have been impressed by the mighty cataracts of water used on the run-out table. This apparent attempt to rival the Fountains of Rome is the outcome of studies which demonstrated the importance of effects of mill-finishing and coiling temperatures on the quality of the finished tinplate. Broadly, the requirements for optimum properties are to finish hot, that is just above the critical range, cool very fast, and coil as cold as is practically possible. Such practice will provide a uniform and reasonably fine ferrite grain size and, most importantly, a cementite distribution suitable for the production of dispersed and well-spheroidised particles in the subsequent annealing operation. Such factors are important mostly from the standpoint of mechanical properties, but are not without effects on corrosion behaviour in certain cases.

Continuous Strand Annealing. Box annealing is still the most widely-used procedure for annealing tinplate steel after cold-reduction. It involves slowly heating the coils of strip to a temperature approaching the lower critical point, followed by soaking for several hours and slow cooling to a temperature at which the coils can safely be exposed to air and handled. When submitted to this temperature cycle, the heavily cold-worked steel recrystallises completely and is fully soft. Finally the required *temper* or stiffness is imparted to the strip by skin-pass or temper rolling. The load of coiled strip processed in one furnace or "cover" is very large, e.g., 250 tons.

The procedure is simple, effective and flexible, but to the progressive steel man it falls short of ideal in two rather important respects. First, it is a very long "static" operation inserted into an otherwise continuous



Courtesy: United States Steel Corpn.

Fig. 1. Schematic diagram of continuous annealing line

series, and this poses problems of floor-space, material routing and scheduling of various qualities. Secondly, completely uniform temperature cycling of the large burden of thin coiled strip is not possible, despite such devices as forced atmosphere circulation and the use of convector plates. It is for such reasons that the thoughts of tinplate technicians turned to the possibilities of continuous single-strand annealing almost as soon as tinplate base began to be produced in strip form.

Notable early ventures in the field were the plants of the Crown Cork and Seal Company in Baltimore, and of Dominion Foundries and Steel Limited in Hamilton, Ontario. These plants were designed for operating speeds of about 100 metres per minute and for outputs, on average tinplate stock, of around 9 tons per hour. More recently, plants engineered for 1,000 ft. (305 m.) per minute on stock up to 1 metre wide have been built. These dimensions suggest an annual capacity of the order of 150,000 tons of average gauge tinplate.

A schematic diagram of the 1,000 ft. per min. line at one of the works of the United States Steel Corpn. is shown in Fig. 1.

It is seen that the plant comprises an entirely usual entry processing unit, an electrolytic de-oiling or cleaning station, an entry looper, the annealing unit proper with its heating, holding, slow cooling, fast cooling and final cooling zones, an exit looper and the exit processing unit. The use in the line of four tension-control units emphasises the great problems inherent in driving 1 metre wide by 0·25 mm. steel strip at 300 metres per minute while at a temperature of say 650°C.

A photograph taken from the exit end of the line is shown in Fig. 2.

A few details of this plant will prove of interest:—

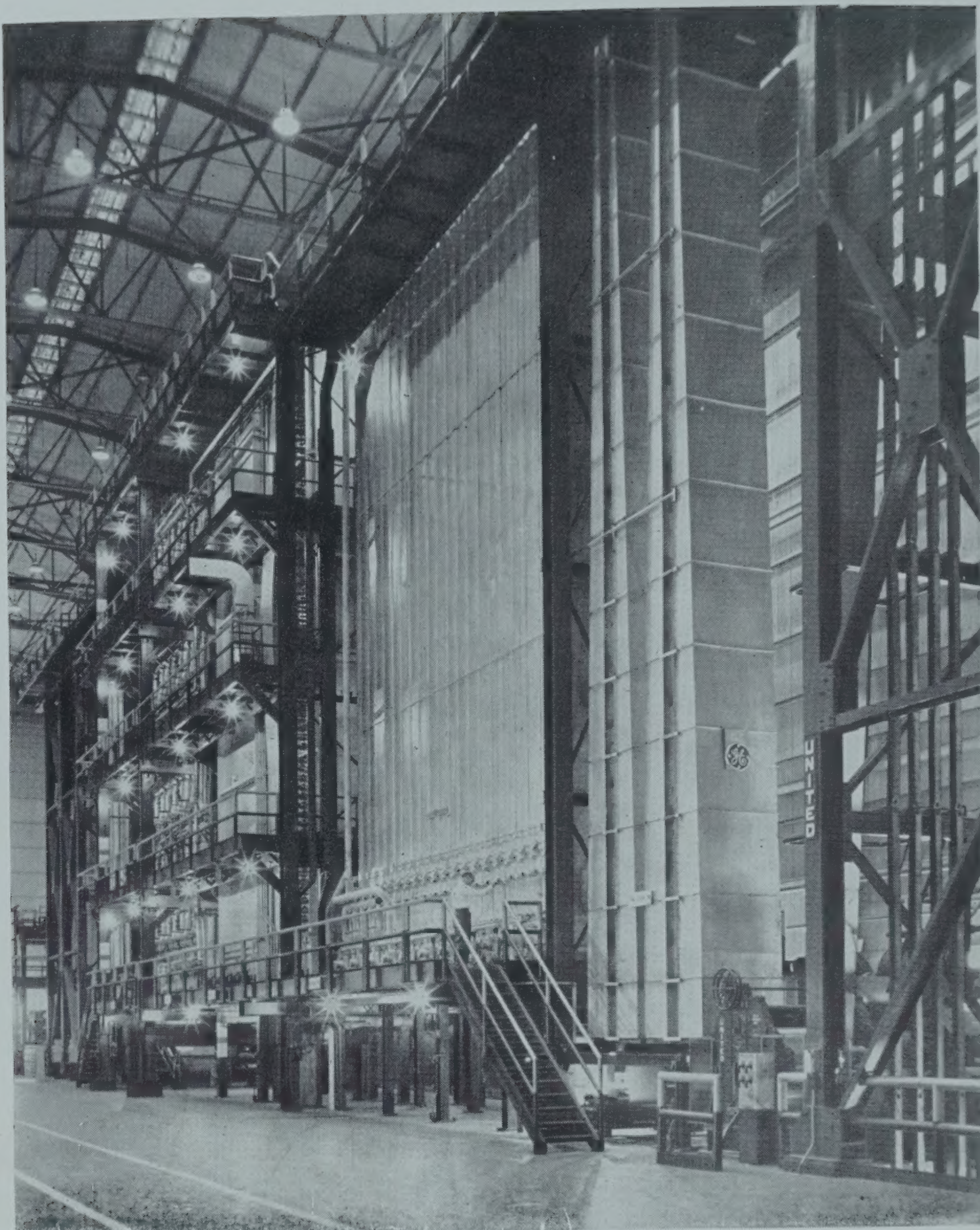
Overall length	100 m. approx.
Height above floor	18 m. approx.
Depth below floor	12 m. approx.
Rated speed	1000 ft. (305 m.) per min.
Length of strip in line	1000 m. approx.
Maximum width of strip	37 in. (94 cm.)

It is recorded that a production figure, for one month's working, averaging 24 tons an hour has been realised on this plant.

The heating zone of the line is fired by gas radiant tubes, while the holding zone employs electrical resistance heaters. Cooling in the slow-cooling zone is by air-tube heat exchangers, and in the fast-cooling zone by a combination of recirculated cooled atmosphere and water jackets. The strip emerges from the fast-cooling zone, and incidentally from the controlled atmosphere section of the line, at about 120°C. Final cooling is achieved by compressed air at ambient temperature.

I had the pleasure of seeing a second plant of this type (but capable of handling strip 99 cm. wide) at one of the works of the U.S.S.C., during its working-up stages. At this works it is planned to anneal a large proportion of the tinplate output on the continuous line.

It is understood that the cost of continuous annealing remains fractionally higher than that of batch annealing though the difference may possibly



Courtesy: United States Steel Corpn.

Fig. 2. 1,000 ft. per minute continuous annealing line for tinplate

be reduced by incorporating the side-trimming operation into the line. First-cost of plant is also high and real advances must thus be proved in order to justify such costs. Easement of material routing and scheduling has already been mentioned. With the elimination of the annealing bottleneck the only important waste-time consumer left in tinplate base processing is cooling after hot-rolling. Aside from this, the process from open-hearth to finished tinplate could occupy as little as thirty-six hours. Uniformity of properties is another notable advantage. Variation of

mechanical properties from inside to outside laps, edges to centres, and coil to coil in a stack, are mitigated in strand annealed stock.

Another "bonus" advantage arises from the different mechanical properties realised in strip that has been quickly raised to a temperature in or about the critical range and as quickly cooled to room temperature. Broadly it may be said that in batch-annealed material the properties of ductility and stiffness are to some extent mutually exclusive. In strand-annealed material they are not. Reference to Table I will help to make this point clear. In batch-annealed material some six or seven distinct temper or stiffness grades (T1 to T6) are required to satisfy the demands of the fabricators. Experience seems to show that with strand-annealed plate quite a number of T3, T4 and T5 requirements will be met with one grade, namely "TU". Moreover, T2 is not outside the bounds of possibility, and indeed I have seen stamped components, normally using T2 batch-annealed stock, successfully fabricated from TU material. Modifications to the cooling cycle may assist further improvements of drawability, but these matters are in a sense *sub judice*, and manufacturers will not wish to be unduly hurried in their notable efforts to increase the universality of tinplate basis.

TABLE I

MECHANICAL PROPERTIES OF TINPLATE

(U.S. Practice)

Temper Number	Associated Steel Types	Typical Uses	Rockwell 30T (after tinning)	Approx. U.T.S. kg/mm²
T 1	L, MR*	Deep drawn cans and components	46-52	33
T 2	L, MR*	Shallower drawn cans and components	50-56	35
T 2½	MR*	Lid rings, etc.	52-58	36·5
T 3	L, MR	Bodies and ends	54-60	39
T 4	L, MR, MC†	Larger and stiffer bodies and ends	58-64	41·5
T 5	MC	Large diameter cans, vacuum cans, etc.	62-68	45
T 6	MC	Beer can ends	67-73	53

* Also Al-killed non-ageing steel. † MC not greatly used in T 4.

Annealing Atmospheres. The subject of advances in annealing practice should not be left without mention of the protective atmospheres used. Comparatively recent researches in the U.S.A. indicated that the corrosion resistance of electrolytic tinplate was in part a function of the annealing atmosphere employed. The effect has been studied by Koehler (among

others) who attributed certain effects to grain boundary oxidation during the annealing operation.

Much tinplate stock is still annealed in the almost traditional atmosphere of so-called DX gas. This is prepared by partially-burning a fuel gas, and contains, besides nitrogen; carbon monoxide, carbon dioxide, hydrogen and methane. The more recently developed NX gas is almost completely burnt fuel gas with carbon dioxide and water vapour removed. Essentially it is nitrogen with a few per cent. of each of carbon dioxide and hydrogen, and a dewpoint of the order of -40°. The even more refined HNX gas is a nitrogen-hydrogen mixture of about the ratio 95:5. It may be prepared from any fuel gas, e.g., methane, by burning it, removing carbon dioxide with monothanolamine, oxidising carbon monoxide to carbon dioxide and again washing out carbon dioxide and finally drying to a low dewpoint.

The use of HNX somewhat enriched in hydrogen has also been suggested.

NX and HNX atmospheres are expensive, costing 10-25% more per unit volume than DX. In processing tinplate stock for low-coating weight electro-coatings the benefaction of properties they confer is, however, deemed to be worthwhile.

ELECTROLYTIC TINNING

One of the outstanding developments in the tinplate industry, and perhaps in the steel industry as a whole, is the development of the electrolytic process for tinning. The history of this development has been well-told already and does not require reiteration. I would, however, call your attention to Table II which shows the present status of electrolytic tinplate installations, and ask you at the same time to bear in mind that twelve years ago the only production came from two pilot lines and was too small even to appear in the statistics. Now we have forty-one lines with a scheduled capacity of about five million tons annually.

The three general types of electrolytic line mentioned in Table II are shown schematically, but all to the same scale, in Fig. 3 (pp. 14, 15).

In the earlier stages of development, strip travel speeds were in the 100 to 200 metres per minute range, but the speeds obtained by modern examples of these lines are astonishingly high. One horizontal acid line is geared for 2500 ft. (820 m.) per minute, while Ferrostan lines are now constructed to realise 1250 ft. (410 m.) per minute maximum speed. These speeds correspond to maximum production capacities approaching 250,000 and 150,000 tons a year respectively. Due to the well-understood characteristics of the stannate electrolyte, plating rate in alkaline lines is lower, and commercially useful production speeds are realised by providing the greater immersed length in the plating section which is clearly seen in Fig. 3. Moreover, higher plating speeds have been achieved by the use of a potassium hydroxide-potassium stannate electrolyte and special anodes, instead of the more traditional sodium hydroxide-sodium stannate solution.

It will be observed that the horizontal acid line does not incorporate a flying shear actually in the line. In fact, in-line shearing has not so far been found possible at speeds greater than about 1000 ft. per minute.

Aside from these great increases of speed and productive capacity, advances have been made both in the pre-cleaning of the strip and in the finishing operations. Notable among the latter are the improvement of the oxide-filming operation and the development of electrostatic oiling.

After the tin coating has been plated on and flow-brightened, it is subjected to a filming or "passivation" treatment which improves its lacquering and decorating qualities and also its resistance to staining and rusting. This treatment involves exposing the tinplate strip momentarily to an oxidising aqueous solution usually containing chromates and phosphates. In recent years, considerable attention has been devoted to this operation, and films of variable resistance and toughness can be applied. This makes possible some degree of matching to users' requirements. These variations in film characteristics are obtained by altering the concentration and nature of the chemical constituents of the solution, by combining simple immersion and electrolytic treatment, and by varying the polarity of the electrolytic treatment.

The oiling operation immediately precedes the final classifying and piling, or coiling step. In this operation an invisibly thin film of a lubricant such as cottonseed oil, palm oil, or dibutyl sebacate, is applied to the filmed tinplate strip. At one time, this oil film was applied by passing the strip through oil-soaked bran. Later, spray-type emulsion oilers were developed, but the newest development is the electrostatic method wherein the strip passes through a vertical chamber filled with a cottonseed oil fog produced by blowing air through a body of warm oil. The density of the fog, upon which the thickness of oil deposited depends, is controlled by varying the amount of vapourising air. Opposite each face of the strip are frames about 2 m. by 1 m., across which fine steel wires are stretched horizontally. The frames are connected to a 50,000 volt source and impart to the fog particles a high potential which causes them to be electrostatically attracted to the strip. The thickness of oil deposited is controlled to one-quarter of a gram per basis box or about twelve millionths of a milimetre. This thin spreading is roughly equivalent to asking Michelangelo to paint the Sistine Chapel with ten grams of paint.

COATING WEIGHTS

The first commercially-operating lines for electro-tinplate were designed, without exception, for the production of the 0·5 lb. grade; that is 0·5 lb. of tin per basis box of 31,360 square inches (approximately 20 square metres) of tinplate. This is equivalent to 11·2 grm. per sq. metre of tinplate and corresponds to a coating thickness of $0 \cdot 77\mu$.

This coating weight was chosen, during the war-time period of tin shortage, for largely non-technical reasons, and more recently, at least in the U.S.A., the production of 0·5 lb. plate has diminished in favour of such grades as 0·25 lb., 0·75 lb. and "100/25" differential plate. It

TABLE II

Plant and Location	Year put in Operation	Type and Number of Lines						Approx. present Capacity Tons per Year ½lb. Plate	Shear in Line	Remarks
		Ferrostan		Horizontal Acid		Alkali				
Gary Sheet & Tin Mill, Gary, Ind.	1937								√	Original capacity, 50,000 decom - missioned 1943
Gary Sheet & Tin Mill, Gary, Ind.	1942	3							√	One rebuilt 1951 for 1-lb. plate, same capacity
Gary Sheet & Tin Mill, Gary, Ind.	1951	1							√	Built primarily for lighter coatings only
Crown Cork & Seal Co., Balt., Md.	1941					1				
Crown Cork & Seal Co., Balt., Md.	1943					1				
Irvin Works, Pittsburgh, Pa.	1942	3							√	
Tennessee C.I. & R R. Co., Fairfield, Ala.	1942	2							√	1 of 3 original lines later rebuilt and transferred to Columbia
Wheeling Steel Corp., Yorkville, O.	1942	1							√	
Wheeling Steel Corp., Yorkville, O.	1951	1							√	
Weirton Steel Co., Weirton, W. Va.	1942			2						3 lines built, one used for zinc exclusively
Weirton Steel Co., Weirton, W. Va.	1949			1						
Jones & Laughlin Steel Corp., Aliquippa, Pa.	1942					2				
Jones & Laughlin Steel Corp., Aliquippa, Pa	1951			1						
Inland Steel Co., Indiana Harbor, Ind.	1942					1			√	
Inland Steel Co., Indiana Harbor, Ind.	1949					1			√	Rebuild of one 1942 line
Youngstown Sheet & Tube Co., Indiana Harbor, Ind.	1942					2				Capacity increased approx. 1947

TABLE II (*Continued*)

Plant and Location	Year put in Operation	Type and Number of Lines						Approx. present Capacity Tons per Year ½lb. Plate	Shear in Line	Remarks
		Ferrostan		Horizontal Acid		Alkali				
Bethlehem Steel Co., Sparrows Point, Md.	1942					3				Rearranging 1951 and 1952 capacity increased approx. 1947
Bethlehem Steel Co., Sparrows Point, Md.	1951					1				
Granite City Steel Co., Granite City, Ill.	1942					1				Capacity increased 1949
Republic Steel Corp., Niles, Ohio.	1943			1						2 lines built, one used for zinc exclusively
Columbia Steel Co., Pittsburg, Calif.	1947	1							√	Originally installed at T.C.1
Columbia Steel Co., Pittsburg, Calif.	1952	1							√	
Fairless Works, Morrisville, Pa.	1952	1							√	
Kaiser Steel Corp., Fontana, Calif.	1952	1								Capacity increased 1954
U.S.A. TOTAL		15		5		13		3,845,000		
Richard, Thomas & Baldwins, Great Britain	1947	1							√	
Steel Co. of Canada, Hamilton, Ontario	1948	1							√	
Dominion Foundries & Steel Co., Hamilton, Ontario	1949	1							√	
Ferblatil, Belgium	1951	1							√	
Steel Co. of Wales, Great Britain	1952	2							√	
Sollac, France		1							√	
National Steel Co. of Brazil, Brazil	1953	1							√	
WORLD TOTAL		23		5		13		4,755,000		

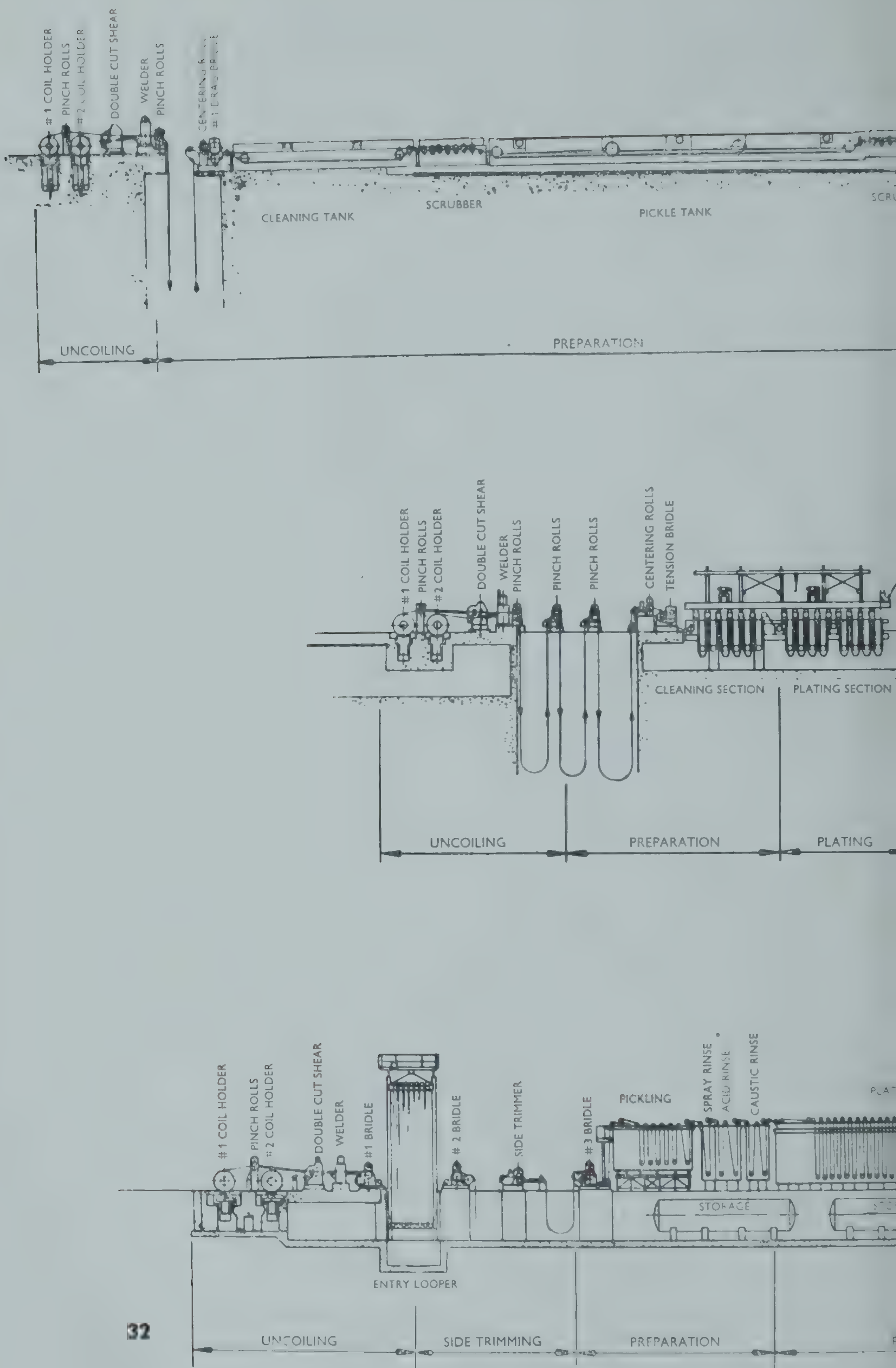


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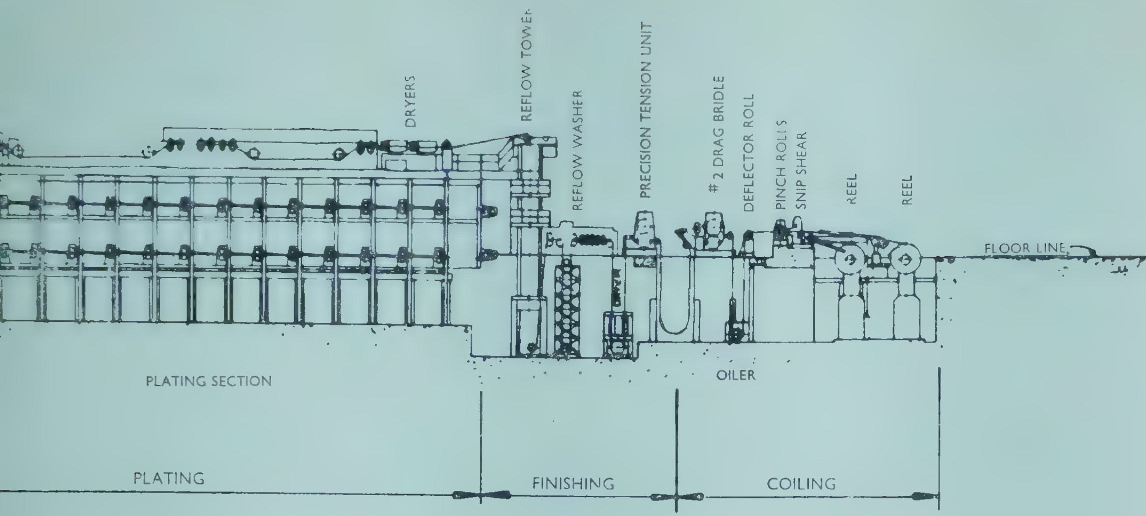
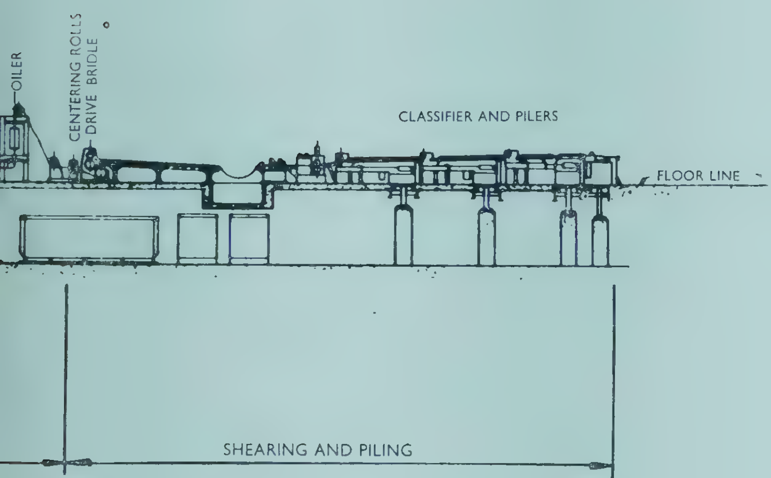
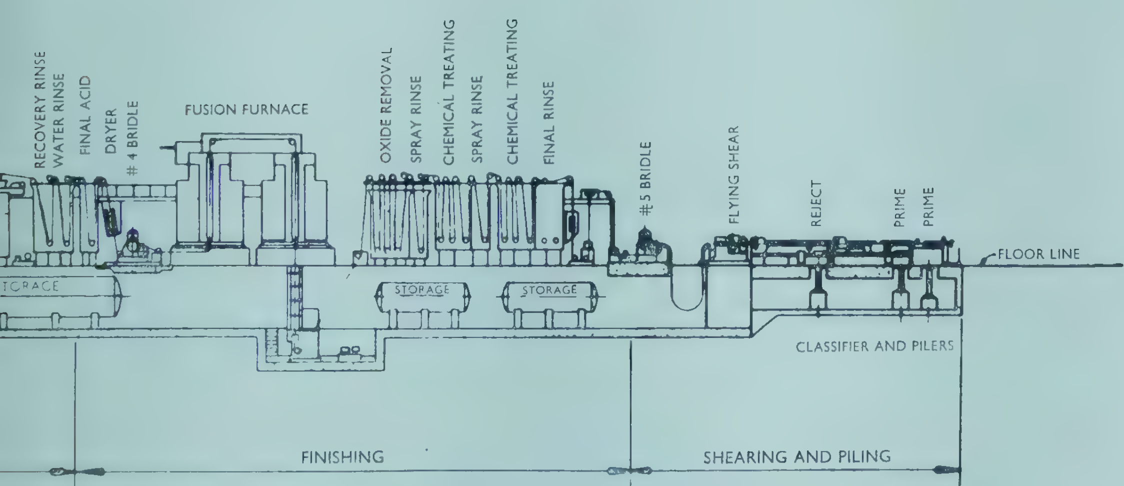
Fig. 3. Schematic diagrams of the three general types of electrolytic tin
vertical acid or Ferrostan line; and the low







Courtesy: Wean Engineering Company, Inc.

e upper diagram is a horizontal acid or 'Halogen' line; the middle diagram is a
lkaline line. All are schematically to the same scale.

TABLE III

COATING WEIGHTS AND APPROXIMATE YIELD FIGURES FOR ELECTROLYTIC TINPLATE AND FOR HOT-DIPPED CANNING GRADES

Name	Designation			Actual Coating Weight			Line or Pot Yield (approx.)	
	U.K.	U.S.A.	France	oz./basis (U.K.)	lb./basis (U.S.A.)	g./m² (France)	lb./basis	g./m.²
Electrolytic	C 4	No. 25	—	4	0·25	5·6	0·29	6·5
Electrolytic	C 8	,, 50	—	8	0·50	11·2	0·55	12
Differential	—	,, 100/25	—	8/2	0·50/0·125	11·2/2·8	0·75	17
Electrolytic	C 12	,, 75	—	12	0·75	16·8	0·81	18
Electrolytic	C 16	,, 100	—	16	1·00	22·4	1·10	25
Coke (U.K.)	Coke	—	—	16*	1·00	22·4	1·14	26
Common cokes (U.S.A.) ..	—	1·25 lb.	—	17·6	1·10	25	1·25	28
Special coke A (U.K.) ..	C 20		27 g./m.²	20	1·25	27	1·4	31
Qualité courante (France) ..								
Standard cokes (U.S.A.) ..	—	1·50 lb.	—	21·6	1·35	30	1·5	34
Special coke B (U.K.) ..								
Qualité special A (France) ..	C 24	1·70 lb.	33 g./m.²	24	1·50	33	1·7	38
Best cokes (U.S.A.)								
Special coke C (U.K.) ..	C 28	—	40 g./m.²	28	1·75	40	1·95	44
Qualité special B (France) ..								
'Kanners' special cokes (U.S.A.)	—	2·00 lb.	—	29	1·80	40	2·0	45
Qualité special C (France) ..	—	—	49 g./m.²	35	2·2	49	(2·45)	(55)
1	2	3	4	5	6	7	8	9

* Common usage but not definitely specified

is possible too, that we shall see the development of a 0·35 lb. grade soon. Modern electrolytic lines admit no difficulties in producing any or all of these grades, except perhaps for the unsolved problem connected with distinguishing absolutely effectively between the two surfaces of differentially-coated tinplate. The future picture, provided that the dark stresses of war do not intervene, must thus be largely dictated by the technological and economic requirements of the user.

In tinning, whether by hot-dipping or electrodeposition, the weight of tin on the tinplate is always *less* by a small amount than the amount consumed in manufacture. The tin on the plate is called the *coating weight*, while the amount consumed in manufacture is called the *pot-yield* (hot-dipping), or the *line yield* (electrodeposition). The difference is, of course, due to losses, some recoverable, in the form of dross, scruff, sludge, etc. From time to time confusion arises due to different ways of expressing the quality or grade and some attempt is made in Table III to show the relationships between some of the more important qualities. It may be mentioned that the likelihood of confusion is perhaps lessened if it is remembered that in all three countries electrolytic tinplate is designated by coating weight. In the U.K. and in France this is true also for hot-dipped plate. In the U.S.A., however, hot-dipped tinplate is designated by its pot-yield. One can only hope and strive for an eventual elimination of such anomalies and for the speedy outlawing of such outmoded and useless terms as "coke" and "charcoal".

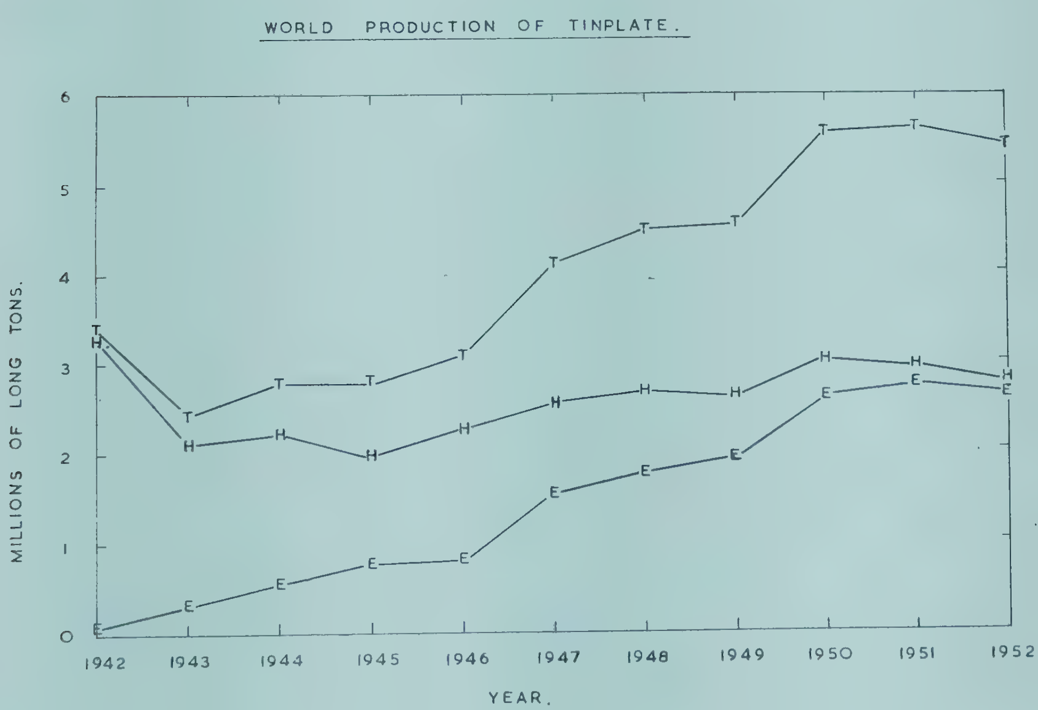


Fig. 4. World Tinplate Production. H, Hot-dipped; E, Electrolytic; T, Total

HOT-DIP TINNING

The long-established hot-dipping process has, in recent years, been somewhat overshadowed by the almost explosive development of the electrolytic method. Nonetheless, a vast quantity of tinplate continues to be manufactured by the older process as Fig. 4 clearly shows. Moreover, many new installations for hot-dip tinning have been made in recent years and the technique of the operation has been improved so that modern equipment is very different from that of twenty years ago. Better engineering design, improved methods of firing, and automatic control of palm oil and of cleaning solutions are among the advances which have permitted the use of higher speeds now approaching 13 metres per minute, higher yields of prime-quality plate and better tin economy.

A modern hot-dip tinning line such as that shown schematically in Fig. 5 may comprise a dry-plate feeder, the pickling section, a single sweep tinning machine, wet and dry cleaning stations and equipment for assorting and piling. In such an arrangement all the units are in tandem and driven synchronously one with another and handle the sheared temper-rolled stock continuously to the final piling of prime quality plate.

Continuous sheet-pickling units, connected to form a part of the tinning unit, have been used in European works for many years. Examples are the Melingriffith machine widely-used in the United Kingdom, and the radial spider type of pickler developed notably by Ets. Carnaud et Forges de Basse-Indre in France. Typical batteries of combined pickling and tinning machines of these types are shown in Figs. 6 and 7.

Such machines, by reason of the relatively long time available for the pickling step, are well able to handle both hot-pack rolled and cold-reduced stock. In works making only cold-reduced base, however, new plants are mostly equipped with straight-through electrolytic picklers which remove the vestigial oxide film from the temper-rolled stock in a few seconds. These units, first developed by the Tennessee Coal Iron and Railroad Company are fed by automatic dry-plate feeders essentially similar to those used, for example, on container-fabricating machines. Fig. 8 shows a modern high-speed automatically fed hot-dip tinning line installed at the Trostre Works of the Steel Company of Wales.

Generally, the sheets fed from the top of the stacks (two or three in number according to the width of the line) are edge-feathered by magnets or air-jets, lifted by suction cups and carried forward by belts to the pickler. They are then passed through a bath of 1 to $1\frac{1}{2}$ per cent. inhibited hydrochloric acid by pairs of driven rollers; the upper one of each pair being a conducting roller of stainless steel or graphite and the lower one of rubber. Electrodes are of steel or graphite and current employed may be about 200 ampères per unit, the sheets being made cathodic. At the exit end of the pickler the plates are squee-geed and spray-rinsed before passing to the Davis feeder rolls of the tin pot. In one installation with which I am familiar, using 1 per cent. HCl at 38°C. with a pickling time of about 5·5 seconds, the plates are very well pickled, having a good satin and evenly-wetted surface.

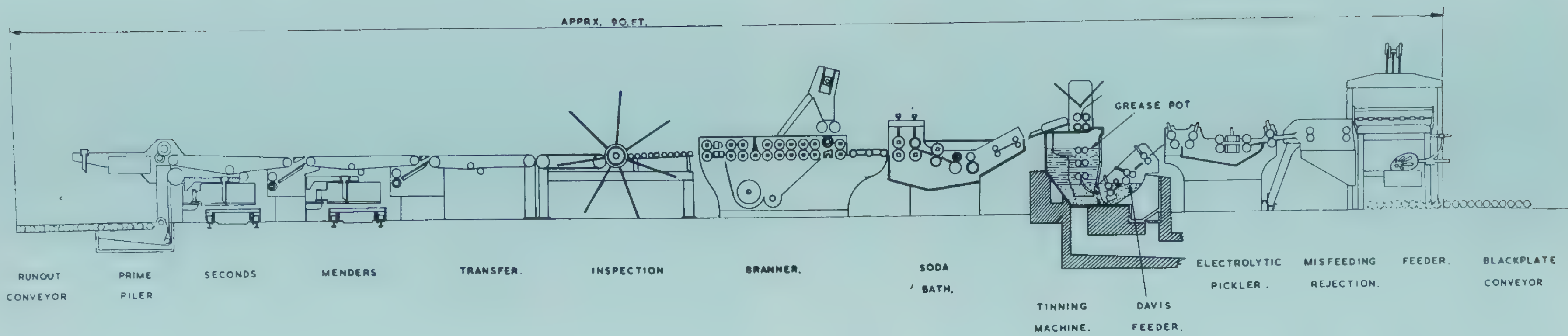


Fig. 5. Sketch of modern Hot-Dip Tinning Line

Courtesy: The Steel Company of Wales, Ltd.

Fig. 6. A battery of Melingriffith tinning units at a South Wales Works. In these units the pickling wheels, which hold the plates between pegs on their peripheries are seen in the background

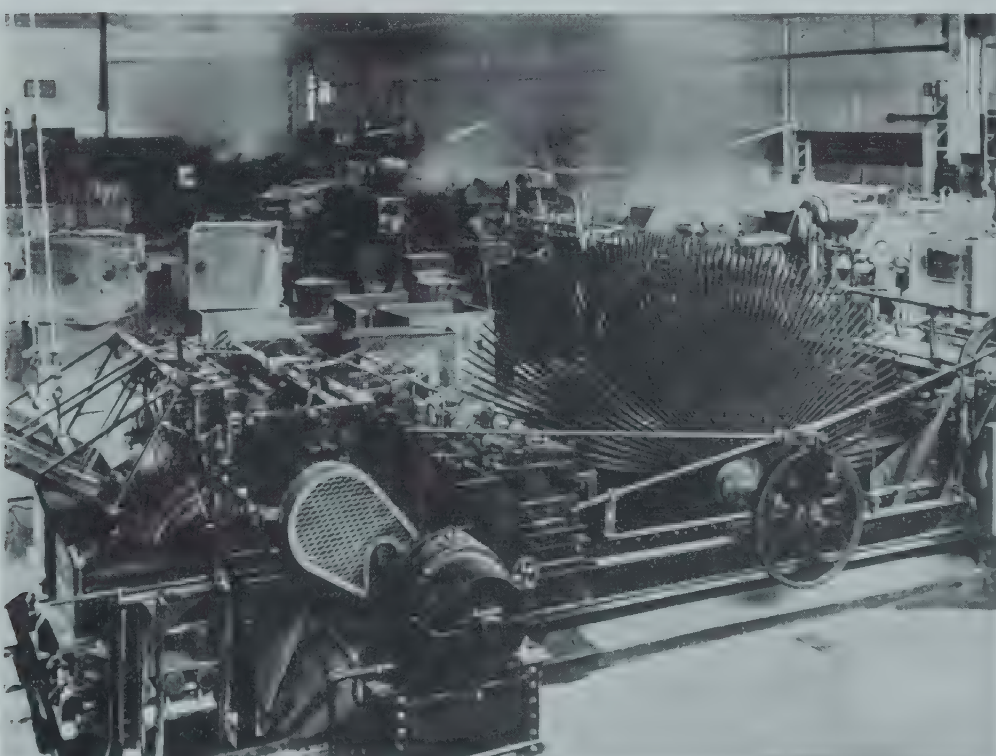
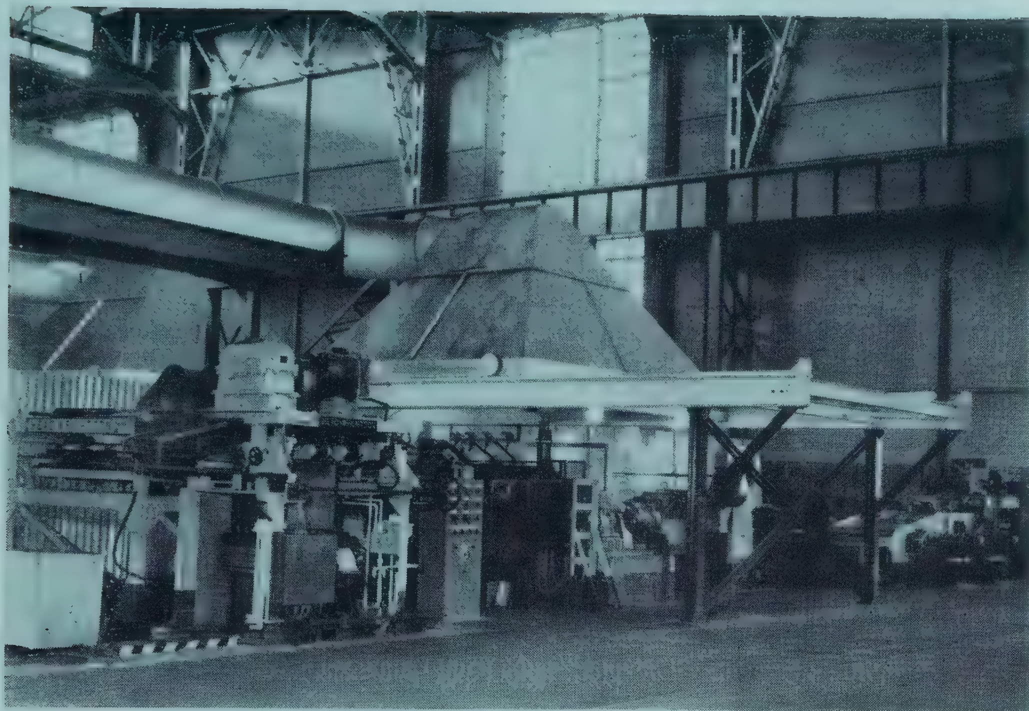


Fig. 7. The tinhouse at the Carnaud Works at Basse-Indre. The pickling wheels hold the plates between spider-like radial arms



Courtesy: The Steel Company of Wales, Ltd.

Fig. 8. View of modern Hot-Dip-Tinning Line. The feeding device is seen at left and the assorting line at extreme right.

In the tinning unit itself, attention has been directed to improving the engineering and metallurgical design, and many of the crudities of older units are now eliminated. Designers have faced such difficulties as increasing speed without increasing coating thickness, and the handling of lighter gauge stock without undue damage. They have also had to tackle the problems inherent in tinning steel stock of very different shape and surface characteristics from the traditional pack-rolled material.

Heating is now usually by electrical or pre-mixed gas-fired immersion type elements. Such systems have enabled the ready establishment of the required temperature gradient through the pot, have decreased scruff losses and have provided fuel economies. The palm oil in the grease pot has also come under closer control and in any works having a sizeable battery of tin pots, the oil is brought to the required condition in a centralised system and delivered to the units by heated pipelines and automatic valves as required. The main control test for the oil is usually the measurement of Saybolt viscosity at 99°C. (210°F.) and normal practice is to stabilise the value at around 95-105 SUS.

The rollers of the tinning machine require the most careful engineering if a product of consistently satisfactory quality is to be obtained. Let us consider for a moment the conditions where the sheet of tinplate emerges from the uppermost pair of tinning rollers in the grease pot of the tinning machine. There are four surfaces carrying molten tin, the two surfaces

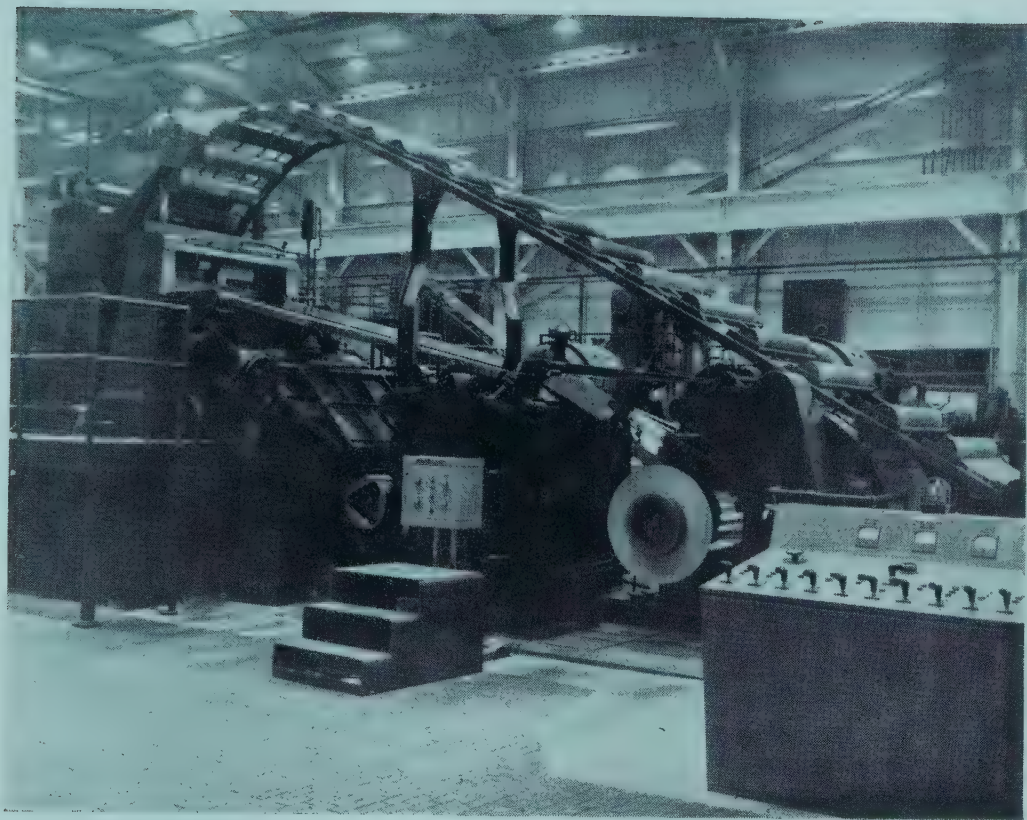
of the tinplate and the surfaces of the two rollers. On the admittedly rough assumption that all the surfaces will carry an equal thickness of molten tin, the "thickness" of molten tin that passes through the bite of the rollers when tinning 1·1 lb. plate is 0·00625 mm. The control required on a pair of rollers typically 2 m. body length by only 11 cm. diameter and moreover working in a bath of palm oil at 240°C., thus constitutes a considerable problem.

The necessary criteria are met by using fairly high-carbon steel rollers, correctly forged and tempered to avoid warpage, ground to a camber calculated according to their body-length, diameter and stiffness, and grooved or "threaded" to increase "tin-carry" where necessary. Moreover, the so-called grease pot brushes must be well matched-up to the rolls and quite free from chips or cracks.

Practice varies from works to works but the general trend is towards the three-roll grease pot machine with rolls of relatively high hardness, e.g., up to 50 Scleroscope, and carbon content above 1·1 per cent. Camber may range from 0·007 in. on a 64 in. by 4 in. roll to 0·019 in. on a 75 in. by $3\frac{1}{2}$ in. roll. Grooving or threading may be between 0·0005 in. and 0·001 in. deep and at a pitch of 0·2 to 0·1 in. according to the coating weight required and to the position of the rollers in the pot.

The above observations are intended to serve as an example of the greater precision that is gradually being built into the hot-dipping operation. Such precision and control is not by any means limited to the operations and components briefly mentioned above, but has also intervened at all other stages of the process. The effects of these advances have been to reduce operating costs, to reduce the difference between the tin coating weight and pot yield and to increase the yield of prime quality plate. Thus the availability of cold-reduced basis plate has reduced rejects due to steel defects, better engineering and maintenance of the tinning unit has reduced tinning defects, automatic feeders have reduced mechanically damaged plates, in-line picklers have eliminated pickling defects, palm oil control has virtually eliminated palm oil menders, better cleaning has reduced dust and branspots and automatic assorting and piling has reduced inspectors' and packers' handling defects.

Despite these real advances the hot-dip process must continue to develop technically. Speed is still limited by problems of flux and scruff carry-through and by temperature control problems: coating-thickness variation is still a big problem and the universality of the process is curtailed by the difficulty of applying coatings less than about 17 oz. basis at reasonable operating speeds. Approaches to the solution of these problems may be made by attempting to develop a radically different, and perhaps "anhydrous" method of preparing the basis steel for tinning, and by the use of specially-surfaced rollers in the grease pot.



Courtesy: Wean Engineering Company, Inc

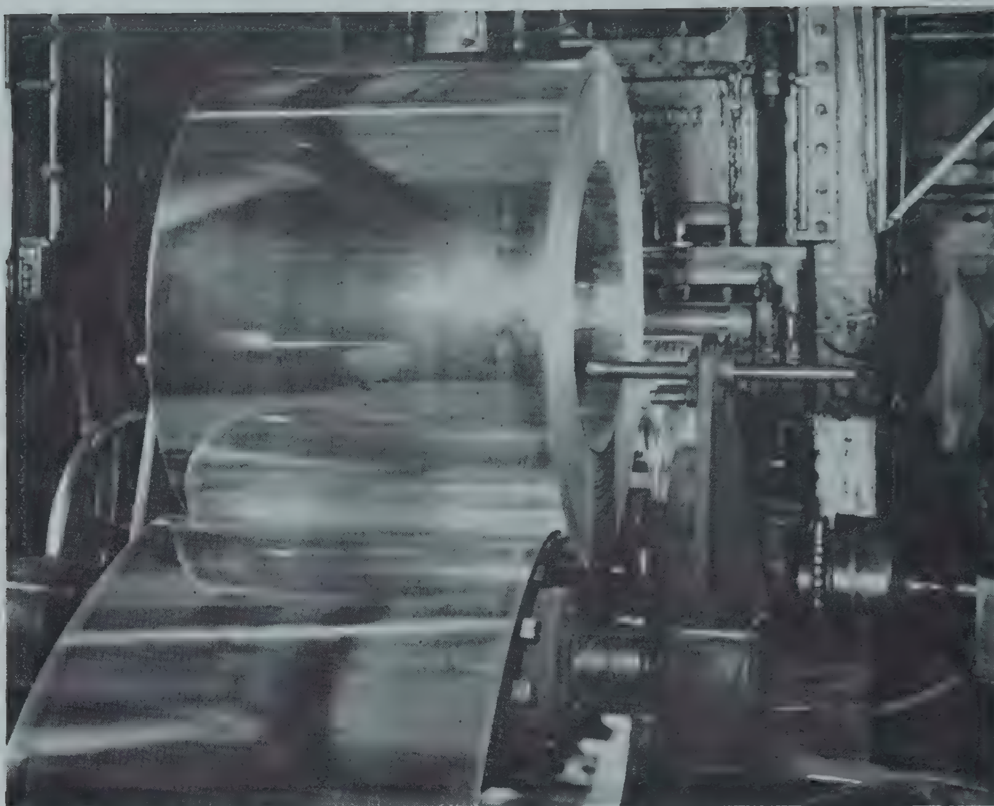
Fig. 9. Electrolytic line equipped for both coiling and shearing. If the material is required to be sheared it passes over a humpback conveyor and goes on to the usual shearing classifying and piling unit. The alternate coiling reels are seen below the conveyor

TINPLATE IN COIL

Most tinplate is shipped to the consumer in the form of sheets cut to specified dimensions and generally of the order 100 cm. by 60 cm. A small proportion of both hot-dipped and electrolytic plate, however, is already being shipped in coil, and in view of the economies effected this tendency will undoubtedly increase. To meet this trend, electrolytic lines may be equipped for both coiling and shearing and Fig. 9 shows a typical arrangement of two exit reels placed under a fly-over conveyor.

Continuously *hot-tinned* tinplate strip is produced in Germany, and trials on a practical scale are at present being carried out in at least two other countries. The process has some inherent advantages and quite a number of practical difficulties. I have no doubt that these difficulties are not insuperable, however, and that relatively inexpensive and flexible plant can be designed for producing hot-dipped tinplate in continuous strip form.

Fig. 10 shows a can-end press operating on a coil feed and this press is only one of many so-equipped at this works.



Courtesy: Crown Can Company

Fig. 10. Container-end press working on coil feed.

TESTING METHODS

This paper deals primarily with manufacturing processes, but a word should be said about advances in testing methods since these procedures are used as much for control of the manufacturing operations as for the final appraisal of product quality and usefulness.

In the category of mechanical tests, we have recently seen the Rockwell indentation hardness test come into wide use as a test for tinplate. Thus the temper scale, which I have mentioned previously, is based on Rockwell numbers using the 30T superficial scale. This test has the great advantages of simplicity, speed and cheapness and certainly excels as a manufacturing control test. Its strongest protagonist would agree, however, that an indentation hardness value does not give a full picture or assessment of plate fabricability. Further advances in mechanical testing must be expected and I would venture to suggest that some form of simple bend test, perhaps not very dissimilar to the traditional Jenkins test, may have an interesting future. The "Flex tester" is an interesting development of this nature.

In the physical and chemical test field, we have seen the development of rapid methods for measuring tin coating thickness. Examples are Bendix's method, which is really a "streamlined" iodine titration method, Kunze and Willey's coulometer method, with its great advantage of providing

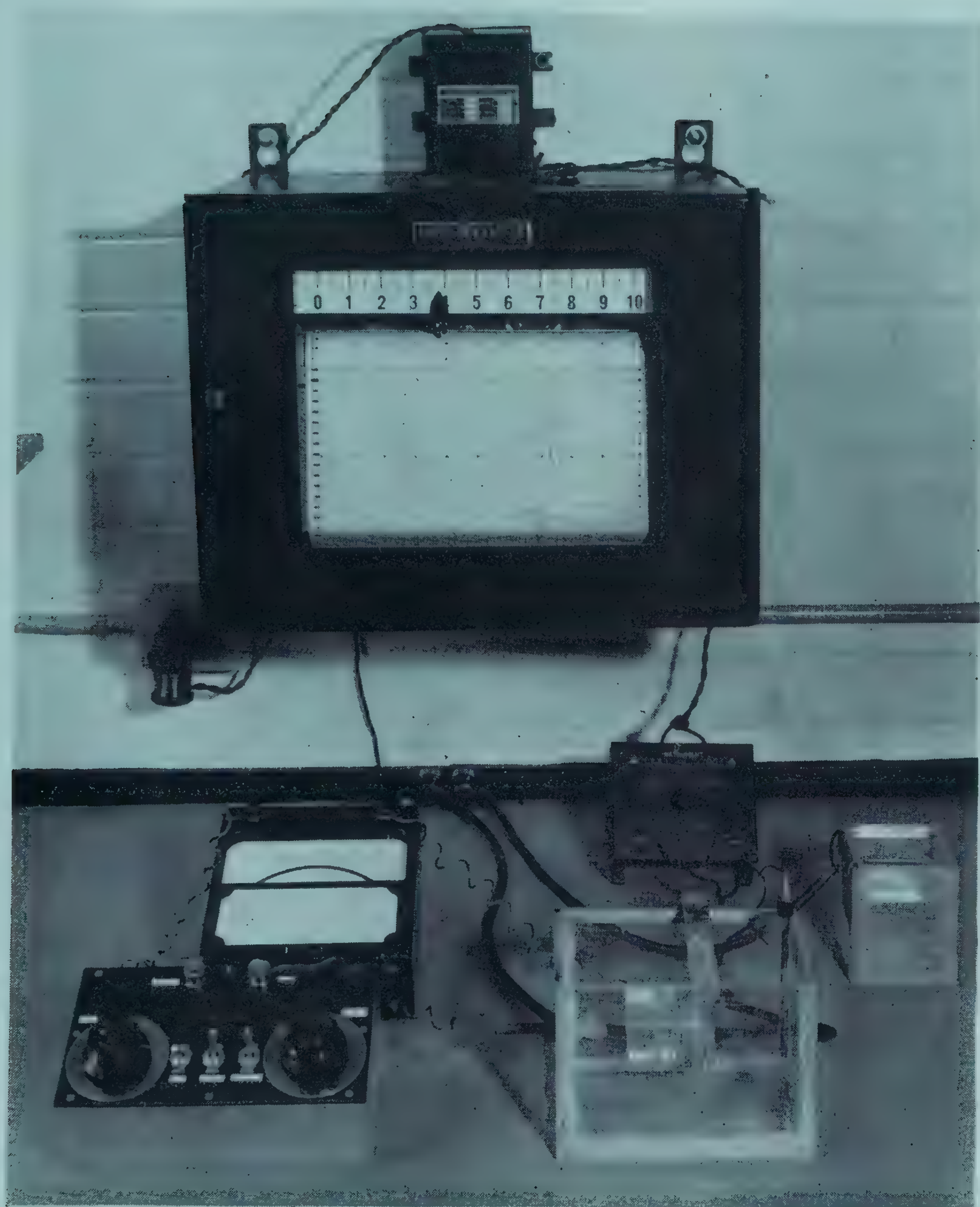


Fig. 11. Apparatus used at the Tin Research Institute for coulombometric tests

values for both free-tin and alloyed tin in a single test, the X-ray fluorescence method with advantages of speed and non-destructiveness, and β-ray back scatter gauges with their ability to work at electrolytic line speeds.

There appears to be a trend now towards using integrating meters possibly backed up with β-ray gauges for electrolytic line control, to employ the coulometer method for laboratory determinations on electrolytic plates and to use the X-ray and sheet-weighing methods for routine control on hot-dip plate. Apparatus used for the coulometer method is shown in Fig. 11.

Fig. 12. Apparatus for corrosion-test studies. The tinplate specimen is held in contact with the corroding medium under strictly-controlled anærobic conditions in a reaction vessel and its potential against a reference electrode is recorded. At the same time the evolved hydrogen is measured by a recording volumeter, and plotted on the strip recorder.

Corrosion resistance tests and porosity tests form a subject of their own and time does not permit a discussion of such newly-developed methods as the pickle-lag test and the iron-solution test. Suffice to say that many workers are presently studying these matters and a clearer picture is slowly emerging. In my own laboratory we are studying the rate of evolution of hydrogen from tinplate while it is being corroded by hydrochloric acid. The apparatus shown in Fig. 12, which was devised at the Tin Research Institute, measures the rate of hydrogen evolution and the electrode potential simultaneously, and is already providing some interesting and indicative results.

CONCLUSION

The tinplate industry has a continuous record of technical achievement and progress, and concerns itself not only with basic improvements of quality, but also makes efforts to cheapen its product to the consumer, to make it better matched to its ultimate purpose, and to increase its availability. These are praiseworthy activities in a world which will increasingly need to use its available resources with the utmost efficiency, and to transport and store its victuals with minimum loss and spoilage.

One might consider an industry such as the manufacture of tinplate to be mundane and devoid of poetry. But to me there is something of inspiration in these vigorous and beautifully-engineered plants, which have as their purpose and task the production of a material which helps to alleviate hunger, overcome emergency, and raise standards of living.

APPENDIX—PLANT CAPACITY

In a country such as this,* with a tinplate production of the order of 30,000 tons per year, you may properly ask, of what interest to us are these large plants with a quarter of a million tons capacity? Such plants indeed are only useful to operators with large home or export markets. As things stand at the moment it would appear that the production of hot-rolled strip is best carried out on a large scale using heavy tandem mills. This is usually not difficult to build into the economy of even a small industrial country since the hot-rolled strip is the starting material for many other products besides tinplate. But following on from the hot strip, cold-reduction can be carried out on single-stand reversing mills as well as on high capacity tandem mills, the unit of plant for annealing can be made within reason as small as desired, and continuous cleaning and pickling lines can also be tailored to the small as well as to the big man. A modern hot-dip tinning set can work efficiently at outputs less than 10,000 tons a year, but a minimum electrolytic line would seem to have an output 5 to 7 times this figure. Certainly the medium-tonnage tinplate producer has reason to desire the development of hot-dipping plant capable of producing a more extended range of coating thicknesses, and of electrolytic plants with a smaller output, but no greater overheads. Whether these developments will come about depends on the urgency of the demand and the ingenuity of the plant manufacturer. Certainly the author has had the pleasure of seeing, in this Continent of Europe, some modern well-engineered tinplate plants producing a product the quality of which is matched to modern criteria and the quantity of which is reasonably matched to the available market.

* Italy.

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Printed in England by W.M.Ltd., London, S.W.1
77895

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